



WEAPONS AND MATERIALS RESEARCH DIRECTORATE

ARMOR MECHANICS BRANCH

BALLISTIC ANALYSIS OF BULGARIAN DUAL HARD STEEL PLATE

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SOFIA, BULGARIA**

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METAL SOLUTIONS FOR TACTICAL VEHICLES



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- **MANY CURRENT ARMORED KITS FOR TACTICAL VEHICLES UTILIZE ROLLED HOMOGENEOUS ARMOR OR HIGH HARD STEEL SOLUTIONS**
- **SELECTION HAS BEEN DRIVEN BY EXPEDIENCY REQUIREMENTS, MATERIAL AVAILABILITY AND COST CONSIDERATIONS**
- **METAL SOLUTIONS ALSO PROVIDE VERY GOOD MULTIHIT FRAGMENT PROTECTION AGAINST IMPROVISED EXPLOSIVE DEVICES DUE TO THE TOUGHNESS OF THE PLATES**
- **ARL IS RE-EXAMINING METAL SOLUTIONS THAT COULD PROVIDE REDUCED WEIGHT AND/OR IMPROVED PROTECTION**



POSSIBLE METAL TECHNOLGIES



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- **IMPROVED STEELS**
 - **ULTRA HIGH HARD STEELS**
 - **DUAL HARD STEELS**
- **HIGH STRENGTH ALUMINUM ALLOYS**
- **ALTERNATE TITANIUM ALLOYS TO TI-6AL-4V**
 - **BETA ALLOYS**
 - **DUAL HARD TITANIUM**
- **METAL LAMINATES**
 - **MILD STEEL/RHA OR HIGH HARD**
 - **STEEL/ALUMINUM LAMINATES**
 - **TITANIUM/ALUMINUM LAMINATES**
- **METAL/POLYMER COMPOSITES**
 - **METAL/POLYMERIC LAMINATES**
 - **METAL/FIBERCOMPOSITES**



DUAL HARD STEEL DEVELOPMENT



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- **DUAL HARD STEEL WAS DEVELOPED IN 1965 AT THE WATERTOWN ARSENAL, NOW ARL, FOR HELICOPTER ARMOR APPLICATIONS**
- **MIL-S-46099A, STEEL ARMOR PLATE, ROLL-BONDED, DUAL HARDNESS WAS ESTABLISHED IN NOVEMBER 1966**
- **PRODUCTION FEASIBILITY STUDIES FOR ROLL BONDED PLATE WERE CONDUCTED BY US STEEL IN 1968 AND THEN AT OTHER COMPANIES**
- **ALLEGHENY LUDLUM IS THE ONLY CURRENT PRODUCER OF K12[®] DUAL HARD ARMOR STEELS USING A PROPRIETARY PROCESS**



ALLEHGENY LUDLUM K12® DUAL HARD STEEL



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- **K12® DUAL HARD STEEL RESULTS FROM ROLL BONDING TWO NI-CR-MO PLATES THAT PRODUCE A HIGH HARDNESS FRONT SIDE AND A SOFTER BACK SIDE**
- **THE FRONT PLATE HAS A HARDNESS OF 601-712 BRINELL WITH THE REAR PLATE 461-534**
- **K12® IS NORMALLY FURNISHED IN THE ANNEALED STATE FOR SHAPING AND CUTTING AND IS THEN FINAL HEAT-TREATED**
- **MIL-S-46099C HAS A BALLISTIC ACCEPTANCE CRITERIA WITH PLATES FROM 0.170"-0.330" TESTED WITH THE 0.30-CAL APM2 AND PLATES FROM 0.290"- 0.585" WITH THE 0.50-CAL APM2**



RESEARCH GOAL



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- **DUAL HARD STEEL ISSUES:**
 - **DEBONDING OF ROLLED PLATES**
 - **PLATE SIZE LIMITATIONS**
 - **REAR PLATE DEFORMATION**
 - **ALTERNATE FABRICATION TECHNOLOGIES**
- **EXAMINE MIL-46099C FOR POSSIBLE ADDITION OF A NEW HARDNESS SPECIFICATION**
- **PAPER PROVIDES THE INITIAL RESULTS OF ARL'S EXAMINATION OF DUAL HARD STEEL PRODUCED BY THE ELECTROSLAG REMELTING PROCESS AS DEVELOPED BY THE INSTITUTE OF METAL SCIENCE (ISM) OF THE BULGARIAN ACADEMY OF SCIENCES**
- **BASELINE RHA AND HIGH HARD WERE ALSO RETESTED AS HISTORIC DATA IS INCOMPLETE**



BULGARIAN INSTITUTE OF METAL SCIENCE DUAL HARD STEEL



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- **ELECTROSLAG REMELTING (ESR) PROCESS WAS HIGHLY DEVELOPED IN THE 1980'S, BUT WAS NOT WORKED ON AT THE ISM AFTER 1991 FOR LACK OF FUNDS**
- **ARL EXAMINED ISM DUAL HARD PLATES IN 2004 AND CONTRACTED WITH ISM TO RESTART THEIR ESR FURNACE AND PRODUCE A MODIFIED VERSION OF US DUAL HARD STEEL**
- **ARL SPECIFIED A FRONT PLATE WITH A HARDNESS OF 500-560 BRINELL WITH THE REAR PLATE 340-370 BRINELL**
- **PAPER EXAMINES THE BALLISTIC PROPERTIES OF DUAL HARD PLATE COMPARED AGAINST RHA AND HIGH HARD STEEL**



ISM ESR016 ELECTROSLAG REMELTING FURNANCE



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**INGOTS WERE ESR CAST
FORGED AND ROLLED
HEAT-TREATED AND CUT
300mm X 300mm PLATES**

**PLATES WERE FABRICATED IN
THICKNESSES OF 5mm TO 80mm**

**ONLY 5-10mm PLATE DATA
PROVIDED IN THIS PAPER**

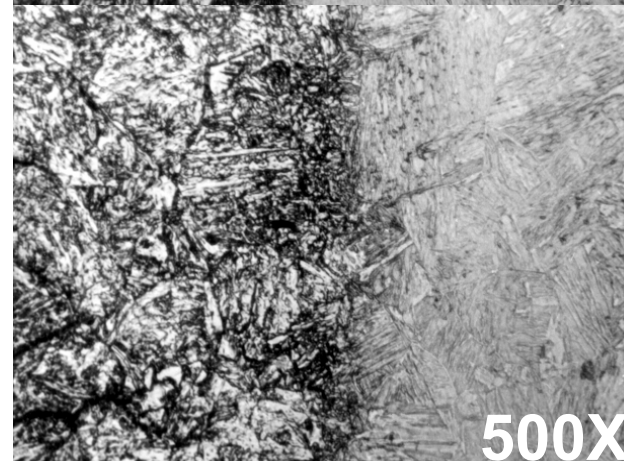
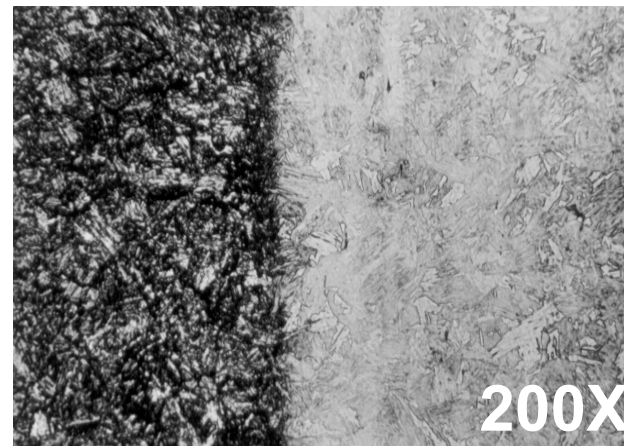
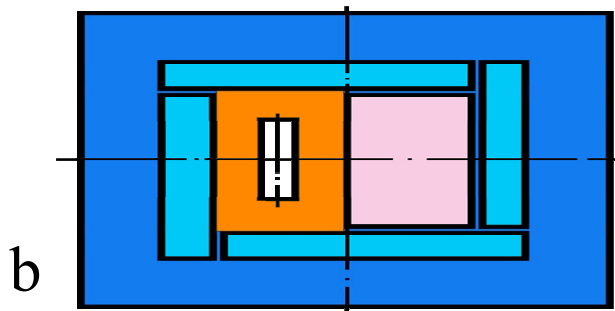
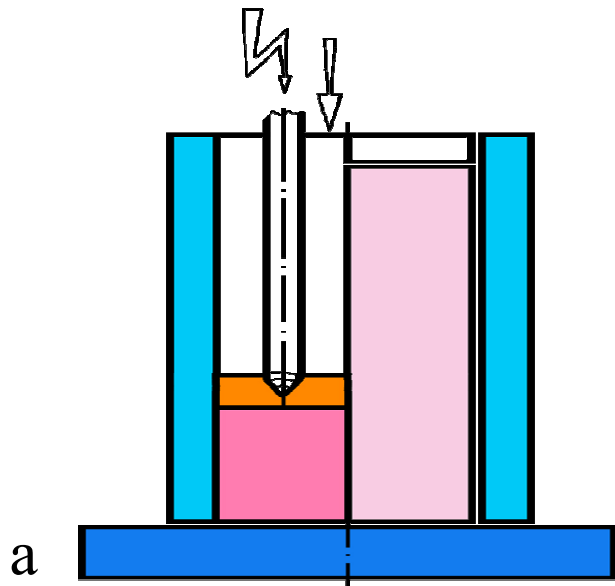


ISM ESR016 ELECTROSLAG REMELTING FURNANCE



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SOFT **HARD**
330-370BHN **520-570BHN**

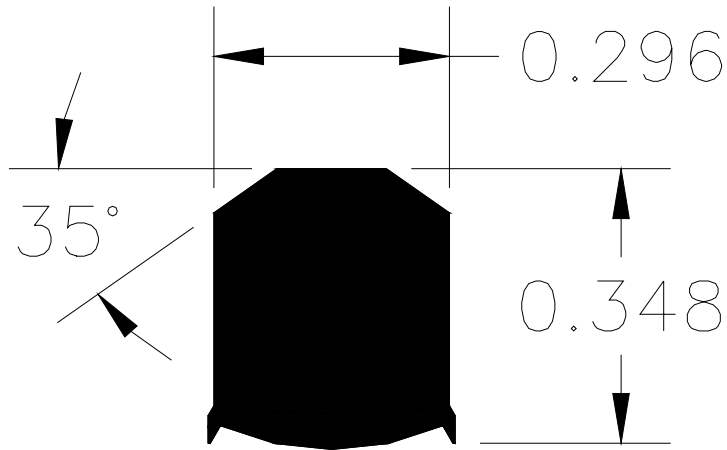


TEST PROJECTILES



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**0.30-CALIBER 44-GRAIN
FRAGMENT SIMULATING
PROJECTILE**

**7.62mmx63 (0.30 CALIBER)
APM2 ARMOR PIERCING
PROJECTILE**



DUAL HARD TEST DATA



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0.30-cal FSP V ₅₀ VELOCITY AT THICKNESS (0° OBLIQUITY) (m/s)						
Nominal Thickness	5mm	6mm	7mm	8mm	9mm	10mm
Actual Thickness	5.39	6.45	7.54	8.23	9.96	10.95
Front/Rear Hardness	523/365	572/375	561/373	537/363	544/340	557/337
Bulgarian Dual Hard	708	763	911	1063	1145	>1402

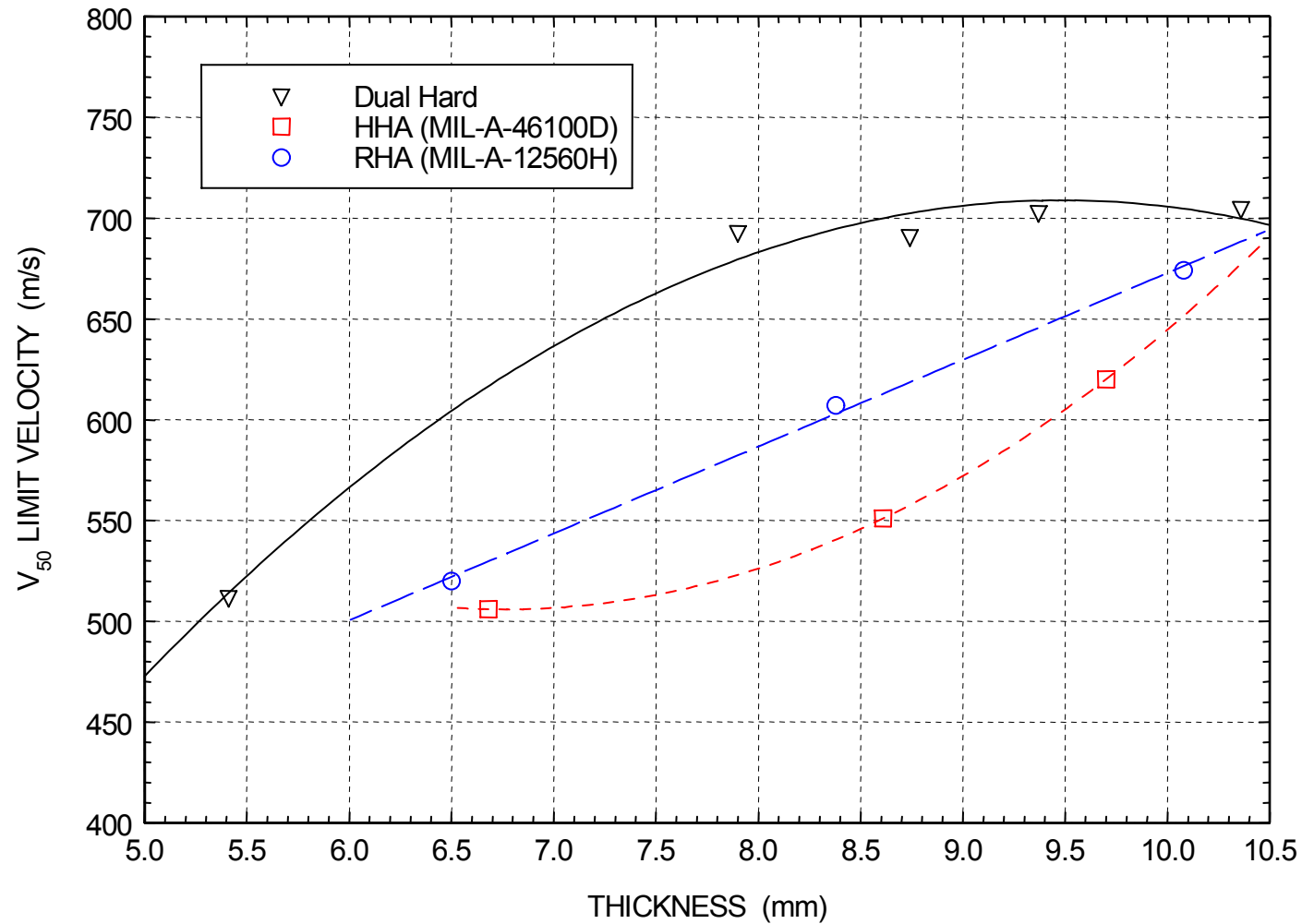
.30-cal APM2 V ₅₀ VELOCITY AT THICKNESS (0° OBLIQUITY) (m/s)						
Nominal Thickness	5mm	6mm	7mm	8mm	9mm	10mm
Actual Thickness	5.41	6.45	7.90	8.74	9.37	10.36
Front/Rear Hardness	523/365	572/375	568/366	547/361	531/340	539/345
Bulgarian Dual Hard	512	NA	693	691	703	705



0.30 CALIBER APM2 @ 0°

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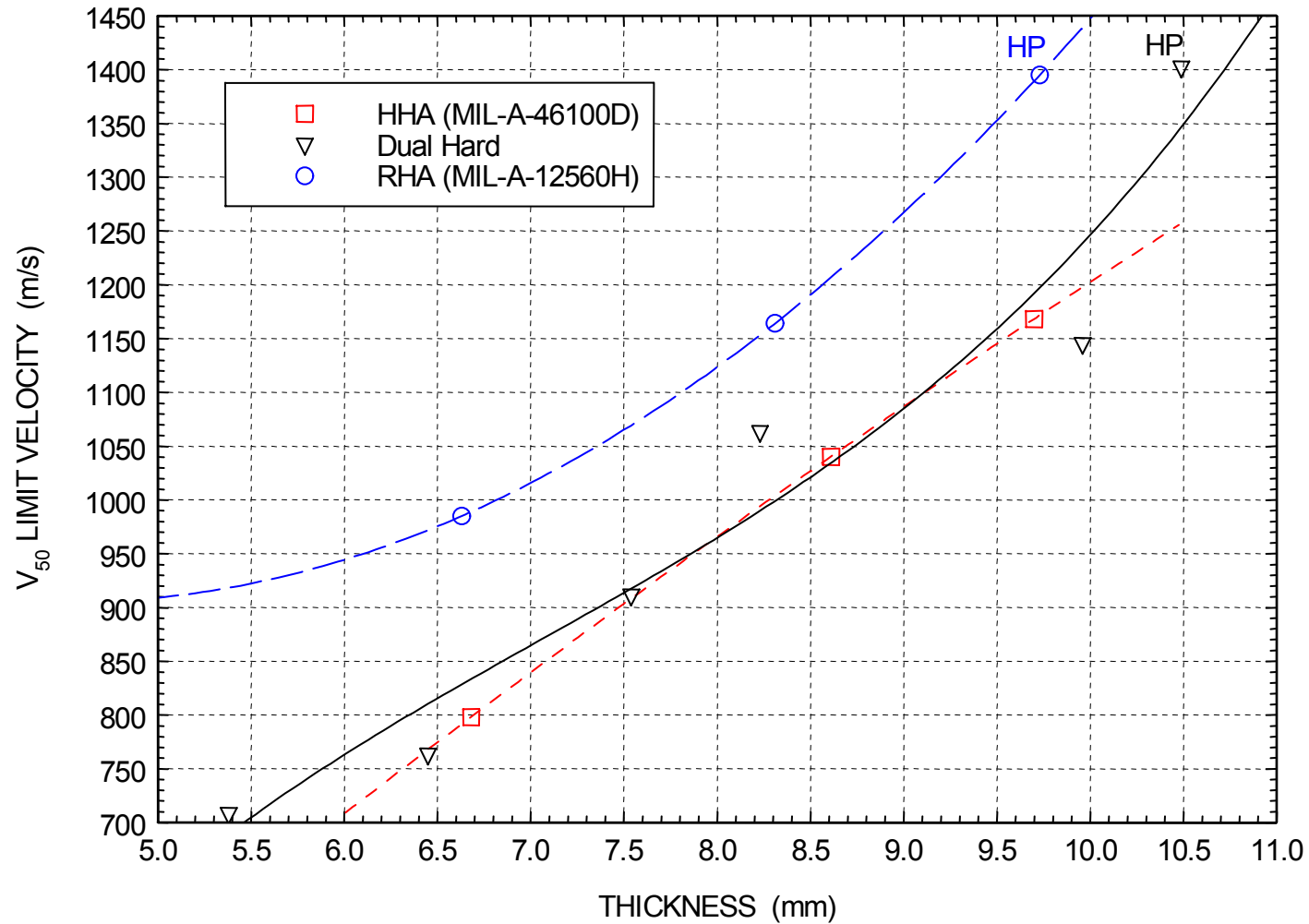


0.30 CALIBER FSP @ 0°



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10mm TEST PLATE

0.30-CALIBER FSP



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FRONT



REAR